NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE RELIABILITY MANDATE: OPTIMIZING THE USE OF HIGHLY RELIABLE PARTS, MATERIALS, AND PROCESSES (PM&P) TO MAXIMIZE SYSTEM COMPONENT RELIABILITY IN THE LIFE CYCLE

by

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June 2002

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: The Reliability Mandate: Optimizing The Use Of Highly Reliable Parts, Materials, And Processes (PM&P) To Maximize System Component Reliability In The Life Cycle			**5. FUNDING NUMBERS**
6. AUTHOR(S) Darin E. Kruse			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT *(maximum 200 words)*

Demonstration of required reliability performance levels prior to system fielding has remained a challenge for the Army, and in recent years, the success rate of systems achieving their stated reliability performance in operational tests has declined. Realization of required reliability performance necessitates effective management strategies and techniques in order to reduce risks. "Designing-in" reliability up front is one of the critical elements to insure adequate system level reliability. It has also been ranked as one the top reliability problems by Program Managers. One design technique for maximizing inherent reliability is through the use of highly reliable parts, materials, and processes. Reliable parts, materials, and process are the building blocks of the total system reliability. They also have a significant role in overall program success because of the contribution to cost, schedule and performance goals.

This research concentrates on the impacts of highly reliable parts and materials on the overall reliability of a weapon system. To gather these data, the researcher drew directly from experiences of part, material, and process professionals from the Army, Navy, Air Force, and contractors with whom they interface. Results show that the key to success resides in early involvement of part, material, and process experts along with a process that facilitates communication and open dialogue. Maximizing inherent reliability is the desired end state.

14. SUBJECT TERMS: Reliability, Weapon System, Parts, Materials			**15. NUMBER OF PAGES** 87
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

SN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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THE RELIABILITY MANDATE: OPTIMIZING THE USE OF HIGHLY RELIABLE PARTS, MATERIALS, AND PROCESSES (PM&P) TO MAXIMIZE SYSTEM COMPONENT RELIABILITY IN THE LIFE CYCLE

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 2002

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ACKNOWLEDGMENTS

The author would like to acknowledge the contributions provided by all the individuals within the Parts, Materials, and Processes community. The precious time they took to provide their support, insights, expert knowledge, and candor on PM&P Program issues were invaluable to this study. In particular, special appreciation goes to the Electronic Parts/Processes Technology Team at the U.S. Army Missile Command, including Mr. David Locker. Without their support, this thesis would not have been possible. Additionally, the author would like to thank his thesis advisors, RADM (ret) Donald R. Eaton, and Kenneth Doerr, for their guidance and patience during the research and writing phases of this study. Finally, the author is most grateful to his wife and children for affording him understanding and support as he worked to complete his Masters Degree and this thesis.

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I. INTRODUCTION

A. BACKGROUND DISCUSSION

The Army Vision, announced in October 1999, is to transition the entire Army into a force that is strategically responsive and dominant at every point on the spectrum of operations. This equates to a need for high readiness levels for rapid deployment, as well as a significantly reduced logistics footprint in the battlespace without jeopardizing combat capability. One enabler for achieving this is highly reliable systems. Highly reliable systems are force effectiveness multipliers, as the resulting benefits contribute towards reduced maintenance times, increased system availability, reduced training and manpower, fewer spare parts, and a net reduction in total ownership costs (TOC) that will free up scarce funds needed for Army modernization.

Demonstration of required reliability performance levels prior to system fielding has remained a challenge for the Army. According to the Army Test and Evaluation Command (ATEC), the success rate for systems in operational testing over a five-year period from 1996 to 2000 was only 20 percent. [Ref. 1] The failure of a weapon system to meet its predicted reliability levels could have a severe impact on its future logistics and life-cycle support costs. According to a recent analysis performed on the Army Comanche helicopter, missing predicted reliability goals by just one percent could result in an increase in lifecycle O&S costs of over $75 million. [Ref. 2]

The reliability development process is composed of many elements (e.g., a PM&P Program, Materials and Processes, Test and Evaluation, Design, Design Interface, utilization, etc.), including the management process of establishing a reliability factor for the system. This management process is such a crucial part of the development process because, as reliability is allocated among the subsystems, it becomes a design driver. A program can have a strong PM&P Program, T&E, etc., but if an unrealistic reliability factor is established, the program will not have a reliable system, nor will it have achieved its reliability requirement. As a rule, reliability is generally overstated, and the impacts on test, support, inventory, personnel, and training can be harmful. [Ref. 3]

"Designing in" reliability up front is one of the critical elements to ensure adequate system level reliability. It has also been ranked as one the top reliability problems by Program Managers. [Ref. 1] One design technique for maximizing inherent reliability is the use of highly reliable parts, materials, and processes. Reliable parts, materials, and processes have a significant role in overall program success because they contribute to the ability to meet cost, schedule and performance goals. One of the techniques to assure the use of highly reliable parts, materials, and processes is through the use of a Parts, Materials, and Processes (PM&P) Program.

A PM&P Program can be applied in several important ways over the life cycle of a system. An effective PM&P Program is key to mitigating risk associated with the use and disposition of noncompliant hardware, avoiding costly redesigns, attaining costs savings from reduced need for failure analysis, rework, etc. Throughout this thesis, when referring to a PM&P Program, the capitalized acronym will be used. When referring to the parts, materials, and processes themselves, no capitalization will be used and the words will be spelled out.

B. OBJECTIVES AND PURPOSE OF THE RESEARCH

Required reliability performance depends upon effective management strategies and techniques to address reliability risks over the course of a weapon system's development and fielding. This research concentrates on the impacts of highly reliable parts and materials on the overall reliability of a weapon system. In DoD terms, it will focus on essential steps that a Program or Logistics Manager can take to maximize system component reliability. A large part of the effort focuses on giving the reader an understanding of how an acceptable reliability factor is established for the system, the importance of achieving high reliability, and the relationship among reliability, logistics and life-cycle support costs. The objective is to determine how to best maximize the inherent reliabilities of system components through the use of highly reliable parts and materials.

C. RESEARCH QUESTIONS

The Primary research question is twofold: how is the selection of highly reliable parts and materials an essential part of the overall reliability development process, and what critical tactics and strategies can Program and Logistics Managers use to maximize the inherent reliabilities of system components?

Subsidiary research questions are:

1. What technology, tools, and techniques are available to ensure the proper selection of reliable parts and materials?
2. How has acquisition reform changed the way a PM&P Program is managed?
3. To what extent does commercial industry differ in its approach to part and material selection, and can the Military leverage these best practices to improve performance in military systems?
4. How can a Program and Logistics Manager mitigate part and material risks?

D. SCOPE

The thesis focuses on the tactics and strategies that Program and Logistics Managers can use to ensure the highest possible inherent reliabilities of system components. Although the data will originate primarily from Army acquisition professionals, lessons learned should be applicable to the other DoD Services.

The scope is limited to an evaluation of reliability considerations in the system design process from several aspects: (1) the technology, tools, and techniques that are available to ensure the proper selection and use of highly reliable parts and materials; (2) an analysis of how parts and materials are managed under acquisition reform; and (3) the extent to which commercial industry differs in its approach towards part and material selection and how the DoD can leverage these best practices. The thesis concludes with a recommendation for actions or steps a DOD Program and Logistics Manager might take to maximize inherent reliability through the use of highly reliable components.

E. METHODOLOGY

The methodology used in this thesis research consists primarily of two steps. The first step is to demonstrate why a weapon system with a high inherent reliability must be designed using highly reliable parts and materials. The importance of selecting an acceptable reliability requirement will be established. The connection will be made between part and material, reliability, logistics, and life-cycle support costs. Then the thesis explains the benefit of "designing in" reliability and how the selection of flawed system level reliability affects design at the lower levels. Next, the thesis provides an overview of the contemporary reliability environment within the DoD. Acquisition reform, current DoD PM&P Program initiatives, commercial best practices, and contracting methods for effective part and material selection are evaluated using literature reviews and interviews with acquisition professionals. The thesis also addresses program management techniques in the same manner. A comprehensive literature review on the subject of reliability encompasses material and sources that include, but are not limited to:

1. DoD, Army, Navy, and Air Force publications
2. Published academic research papers
3. References, publications, and electronic media available at the Naval Postgraduate School (NPS)
4. World Wide Web Sources (DoD, commercial, academic)
5. Personal communication with School of Business and Public Policy faculty at NPS

The second step entails interviews with subject matter experts (SMEs) in the parts, materials, and processes functional area. Data gathering and analysis were conducted through structured interviews. The analysis synthesized feedback and searched for collective issues from the various SMEs on managing PM&P Program requirements, the coordination that is required, the common issues, reasons why they occur, and how these risks can be reduced. To address the concern of data reliability, the SME had editorial control. The interview answers were typed and given to the SME for review and approval prior to incorporation.

F. ORGANIZATION OF THE STUDY

Chapter I. Introduction: identifies the focus and purpose of this thesis as, well as the primary and subsidiary research questions.

Chapter II: Overview and Background: provides a literature review, giving the reader a basic understanding of the importance of establishing an acceptable reliability factor for the system, achieving high reliability, and the relationship among reliability, logistics and life-cycle support.

Chapter III: Managing a PM&P Program on a Weapon System: presents the data collected from interviews with subject matter experts (SMEs) in the parts, materials, and processes functional area.

Chapter IV: PM&P Program Analysis and Lessons Learned: analyzes and compiles the PM&P Program technologies and tools, the impact of acquisition streamlining, commercial PM&P Programs, and the techniques to mitigate part and material risks.

Chapter V: Conclusions and Recommendations: summarizes the findings of the research and answers the research questions.

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II. BACKGROUND

A. INTRODUCTION

The purpose of this chapter is to provide insight into how a weapon system reliability requirement is developed and to explain its relationship to highly reliable parts, materials, and processes. The chapter first discusses the current reliability trend in the Army. It then describes the PM&P Program as it relates to the acquisition process in order to make the analysis presented Chapter IV more understandable. Next, the chapter details the critical need to determine the proper reliability requirement for the system. It then discusses the importance of achieving high reliability and the relationships among reliability, logistics and life-cycle support costs. The benefits of "designing in" reliability and how those benefits relate to the PM&P Program are reviewed, along with the impact of the system-level reliability requirement on the individual parts, materials, and processes. Former and current DoD policies, as well as commercial PM&P Program practices, are covered.

B. THE CURRENT RELIABILITY TREND WITHIN THE ARMY

According to the Army Test and Evaluation Command (ATEC), the success rate for Army systems either in development or operational testing over the five-year period from 1996 through 2000 was only 41%. In the same five-year period, the system operational test (OT) success rate with respect to reliability was *only 20%.* [Ref. 4] Figure 1 represents operational test events that were used as the basis for demonstrating reliability requirements. All acquisition category (ACAT) levels are represented here. The types of OT events included: field exercises; IOTs, FOTs, LUTs; and combined DT/OT. Points above the diagonal achieved their reliability requirement during testing, while those below did not. Most of the systems failed to achieve their reliability requirement in OT, and the trend appears to be downward.

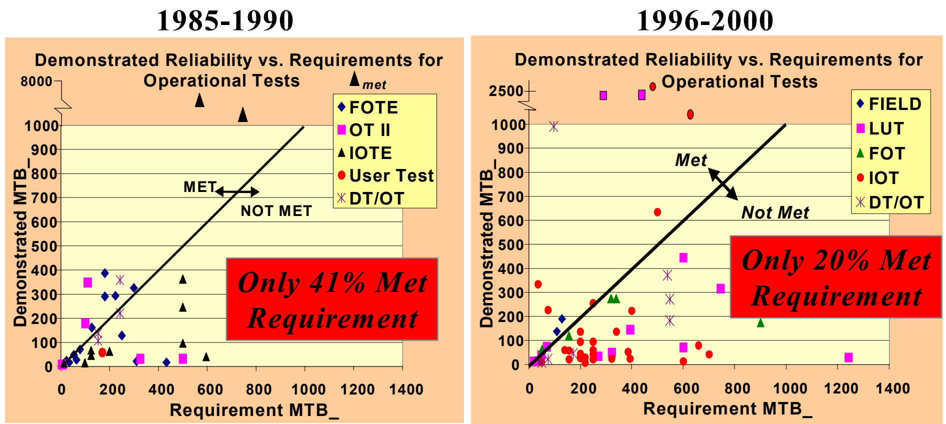

Figure 1. Army System Reliability Performance [From Ref. 5]

C. DESCRIPTION OF A PM&P PROGRAM

There is no universal definition of a Parts, Materials, and Processes (PM&P) Program, although individual definitions for parts, materials, and processes are clearly defined in DOD specifications (e.g., MIL-STD-1547 and MIL-STD-965). For the purposes of this research, a Parts, Materials, and Processes (PM&P) Program is defined as:

> A process that deals with individual Parts, Materials, and Processes requirements. [Ref. 6]

In order to supplement the earlier definition of a PM&P Program, a part is further defined as:

> One piece, or two or more pieces joined together, which is not normally subject to disassembly without destruction or impairment of intended design use. [Ref. 7]

Requirements are defined as:

> Characteristics that individual items must have within a stated environment or a set of conditions as derived from the systems engineering process. [Ref. 6]

The conditions or environments mentioned above are based on the ORD-derived constraints and performance requirements, as reflected onto the individual part, material, or process. Parts, materials, and processes are critical to most acquisitions and are a fundamental element in the achievement of designed hardware performance, which includes:

1. Analysis to support the establishment of comprehensive PM&P Program characteristics from the derived system engineering constraints and performance needs.

2. Establishment of a cross-functional Plan for efficient and uniform implementation of a PM&P Program.

3. Analysis and documentation to support individual part, material, and process needs, consistent with PM&P Program requirements.

4. Development, maintenance, and control of databases documenting design requirements, design baseline, control and use of life-limited (items having a finite shelf life), the basis for decisions made, and control of evolving requirements, so that the impact of changes can be effectively determined prior to implementation.

5. Development of a closed-loop system to efficiently feed back necessary changes derived from system-level performance results and industry data interchange.

6. Development of In-Process or End-of-Line validation processes for known good parts, materials, and processes.

7. Development, maintenance, and control of program-compliant parts, material, and process lists.

A PM&P Program is applied in several important ways over the life cycle of a weapon system. For example, during the Concept and Technology Development and System Development and Demonstration phases of a weapon system, a PM&P Program is applied iteratively as an integral part of system engineering to mitigate risk and tradeoffs between system performance, ease of maintenance and manufacture, cost, production level, parts and materials availability, and technological advancements. Ineffective use of parts, materials, and processes at this early stage of a program may cause unnecessary future program costs and delays. [Ref. 6]

D. ESTABLISHING AN ACCEPTABLE RELIABILITY REQUIREMENT

1. Origination of the Reliability Requirement

Reliability has been defined as "the probability that a system will operate within the designed specified limits for a particular period of time when used in the manner intended". [Ref. 8] In the Army, the reliability requirement starts with the Combat Developer (CBTDEV). The CBTDEV develops the Operational Requirements Document (ORD) and, hence, is ultimately responsible for defining the system's reliability requirements. Typically, these are defined in terms of operational availability and mission duration needs.

Reliability requirements, however, are not developed in a vacuum. Developing quantitative operational reliability requirements, like all other ORD requirements, is a collaborative process between the CBTDEV and the Materiel Developer (MATDEV) using Integrated Product Teams (IPTs). IPTs provide a balanced solution between the best estimate of what will meet the user's effectiveness, suitability, and survivability needs and what is actually affordable and technically possible within program funding, risk, and time constraints. ORD reliability requirements are developed in accordance with AR 71-9 [Ref. 9]. Three key elements combine to define overall reliability performance requirements: list them briefly.

2. Program Manager's Role in the Reliability Requirements Process

Once the overall system requirement is established in the ORD, the DoD delegates the responsibility for implementing the reliability requirement to the Material Developer (MATDEV), who is usually a Program Manager (PM). The PM is responsible for the system acquisition, including the reliability requirement. DoD 5000.2-R states that the "the PM has the task to ensure that reliability, maintainability, and availability activities are established early in the acquisition cycle to assure meeting operational requirements and reduced life-cycle ownership cost." [Ref. 10] The Army further requires the PM to develop and implement an effective Reliability & Maintainability (R&M) program through AR 70-1, which states:

> [An] R&M program will be tailored in scope and content and be designed to ensure that the user operational reliability requirements will be met at confidence levels established by the user.

Finally, DA PAM 70-3 guidance covers aspects of R&M Requirements, R&M Management, R&M Engineering and Design, R&M Testing, and R&M and Assessment Integrated Process Team (IPT) procedures. [Ref. 11] The PM must take a proactive role in establishing systems reliability, starting at program initiation and continuing through the entire program life cycle.

3. Contracting for Reliability

It is the now the PM's responsibility to insure that reliability objectives are translated into quantifiable and verifiable contractual terms. Prior to the advent of military specifications and standards reform in 1994, the work requirements for reliability engineering were usually described in a Statement of Work (SOW) task that required compliance with MIL-STD 785, *"Reliability Program for Systems and Equipment Development and Production."* [Ref. 12] In February 1996, Gil Decker, the Army Acquisition Executive at the time, issued policy on incorporating a performance-based approach to Reliability in Requests for Proposals (RFPs). A key change was that no "how to" reliability standardization documents were to be used. The policy stated:

> Reliability requirements should be included in RFPs by specifying: (1) quantified reliability requirements and allowable uncertainties, (2) failure definitions and thresholds, (3) life-cycle usage conditions. [Ref. 13]

Decker's policy was institutionalized in the update to AR 70-1 in January 1998. AR 70-1 clarified several points of the AAE memo.

Reliability parameters expressed by operational users, and ones specified in contractual documents, take many different forms. User requirements are generally expressed in a variety of forms that include combinations of mission and logistics reliability, or they may combine reliability with maintainability in the form of availability. Conversion from commonly used operational terms, such as mean-time-between-maintenance (MTBM) and mean-time-between-critical-failure (MTBCF), must be made to enable translation to parameters that can be specified in contracts and verified in testing.

In order to verify that a contractor will achieve the system reliability requirement, the PM will also include contract provisions that ensure access to sufficient information for evaluating source data, models, reasonableness of modeling assumptions, methods, results, risks, and uncertainties. [Ref. 14] Also, the test program must be structured so that the reliability requirements can be demonstrated prior to full-rate production. One of the cardinal rules of testing is to verify contractor claims of reliability as early as possible. [Ref. 15] The information used to estimate or determine progress toward meeting R&M requirements must be based on testing in accordance with the system's expected mission profile and operating environment. Reliability-growth projections or other prediction methods are sometimes used in determining that contractual reliability requirements have been met.

4. Reliability Allocation

After an acceptable requirement has been established for the system, it must be allocated among the various subsystems. Reliability allocation involves setting reliability objectives for components or subsystems in order to meet a system-level reliability objective. Reliability allocation should occur in the initial stages of design. A knowledge of technical capability and cost trade-off considerations will help derive optimum allocations, but the simplest method for allocating reliability is to distribute the objective uniformly among all subsystems. For example, consider a simple system composed of two subsystems: subsystem A and subsystem B. Each subsystem is composed of assemblies (assembly A through assembly P). Each assembly is composed of components (component 1 through component 10). The reliability of the system is based on the reliability characteristics of the subsystems; the reliabilities of the subsystems are based on the reliability characteristics of the assemblies; and so forth. At the lowest level (i.e., the component level), reliability is assumed or predicted. [Ref. 16] Figure 2 displays reliability block diagrams for this example—created using a sub-diagram approach—and parameters for each component.

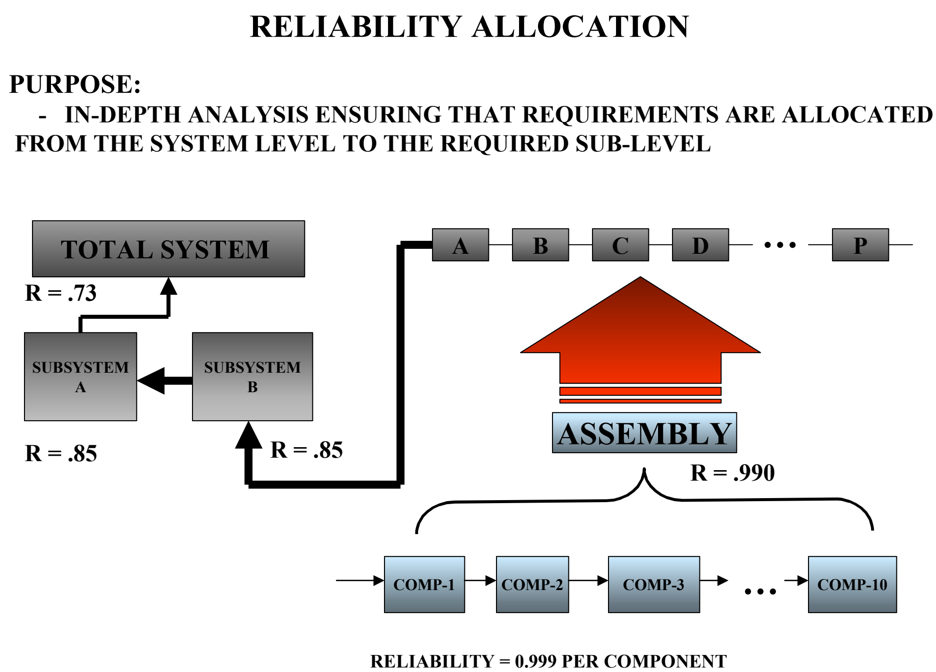

Figure 2. System Reliability Allocation Diagram Example

5. Causes and Impacts of Establishing a Flawed Requirement

One of the greatest challenges designing a weapon system is establishing an acceptable reliability requirement. Sometimes, established reliability requirements are not realistic. Although the PM is supposed to be involved in generating requirements, in reality, R&M Managers from the program office are given little voice during this part of the process. The checks and balances to ensure a proper requirement were either removed as part of acquisition streamlining or are simply not in place. [Ref. 3]

Program offices must also deal with unrealistic contractor estimates. During initial acquisition, the contractor engineers provide reliability estimates that are critical in establishing sparing levels and technical support criteria. Experience has shown that contractors, who are under pressure to win and maintain contracts, use optimistic reliability predictions. [Ref. 17] The null hypothesis of having the contractor verify reliability estimates as accurate computations is seldom enforced. Most weapon systems are cost- and schedule-driven and do not incorporate the time or resources necessary to perform reliability tests on critical sub-systems. [Ref. 3, Ref.17]

The impacts of a flawed requirement are two-fold. Not only will the system have difficulty meeting the requirement during testing, but the development of a sustainment package based upon a flawed reliability factor also will produce sparing shortages, test equipment shortages, and decreased readiness. [Ref. 15]

E. HIGH RELIABILITY AND THE LINK TO LOGISTICS AND LIFE-CYCLE SUPPORT COSTS

The failure of a system to achieve high reliability levels has a severe impact on operation and support (O&S) costs and operational availability (Ao). The impact of reliability on O&S costs is attributable to the high costs associated with acquiring repair and replacement parts. High reliability is fundamental to cost-effective and efficient logistics; it means less support and training and fewer inventory costs and personnel. According to an analysis of the Army Comanche Program, missing predicted reliability goals by just one percent could result in an increase in O&S costs of over $75 million. [Ref. 2] Figure 3 demonstrates the huge O&S costs associated with maintaining some other Army weapon systems. As the chart shows, the potential impact on lowering O&S costs through increasing reliability is enormous.

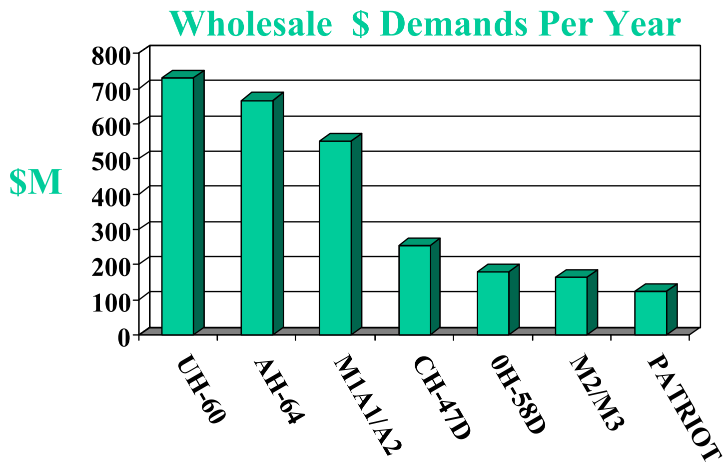

Figure 3. Cost to Support Current Reliability Levels [From Ref. 5]

The impact of reliability on readiness also can be significant. In the Comanche Program, for each five percent below the predicted reliability level for peacetime operations, the Ao decreases by one percent. [Ref. 2] Figure 4 demonstrates the impact of reliability on Army tank availability. The impact is significant, as 45 percent of the tanks were down at one point during the gunnery firing exercise.

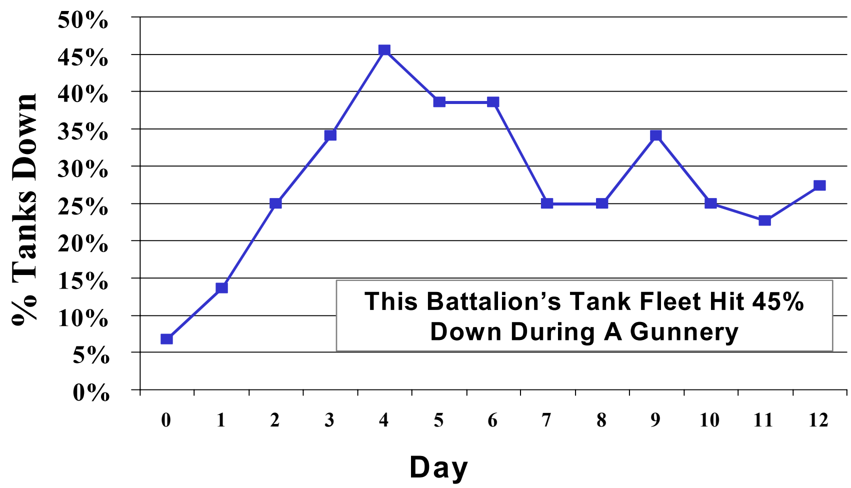

Figure 4. Battalion's Tank Fleet Hit 45 Percent Down During A Gunnery [From Ref. 5]

Reliability also affects troop morale. Because low reliability causes a high failure rate, it makes unrealistic demands on maintenance personnel. Repairs and maintenance may have to be performed very quickly at any time, day or night, in order to meet operational commitments. In such cases, personnel must continue working until the job is done, regardless of how much time it takes. An August 1999 GAO survey of active-duty personnel showed that a significant portion of aviation maintenance personnel worked more than 50 hours a week, and that some worked 70 hours a week. The GAO reported that the majority of factors cited by military personnel as sources of dissatisfaction and reasons for leaving the military were work-related, such as the lack of parts and materials to successfully complete daily job requirements. One example is an aircraft wing with a status report showing that six out of 28 aircraft downed for parts had not flown for 37 days or more. One of these aircraft had not flown for more than 300 days and, according to the Maintenance and Material Control Officer, was missing 111 parts. As a result, the Navy had been unable to use this multimillion-dollar asset for almost a year. [Ref. 18]

When faced with supporting maintenance-intensive weapon systems, technicians and logisticians are initiated into a culture of learning to do *more with less* and performing the mission at all cost. Failure to perform a mission successfully is deemed an unacceptable outcome. Rather than fail, technicians (and commands) resort to shortcuts, work-arounds, and misrepresentations of readiness to feign the appearance of mission readiness. [Ref. 19] To the extent that low reliability causes failures that contribute to extensive overtime, morale and retention will be adversely affected, and additional costs may be incurred in recruiting and training new personnel

F. BENEFIT OF "DESIGNING IN" RELIABILITY

Although the reliability development process consists of many elements (e.g., a PM&P Program, Test and Evaluation, Design, Design Interface, utilization, etc.), the benefit of "designing in" reliability cannot be understated. "Designing in" reliability implies performing up-front analyses during the design phase so that the inherent reliability of the system is as high as possible. As with anything else, being proactive with reliability early in the lifecycle of a system is more cost-effective than dealing with potential schedule delays and unexpected costs of failing a test later, only to have to redesign and test yet again until the problem is fixed. It is critical to make reliability part of the early design because the decisions made during this period have such a great impact on the Life Cycle Cost (LCC). The chance to influence LCC cost reductions grows smaller when projects are converted into bricks and mortar, as Figure 5 illustrates. Making major changes in LCC after projects are turned over to production is not possible because the die has been cast. [Ref. 20]

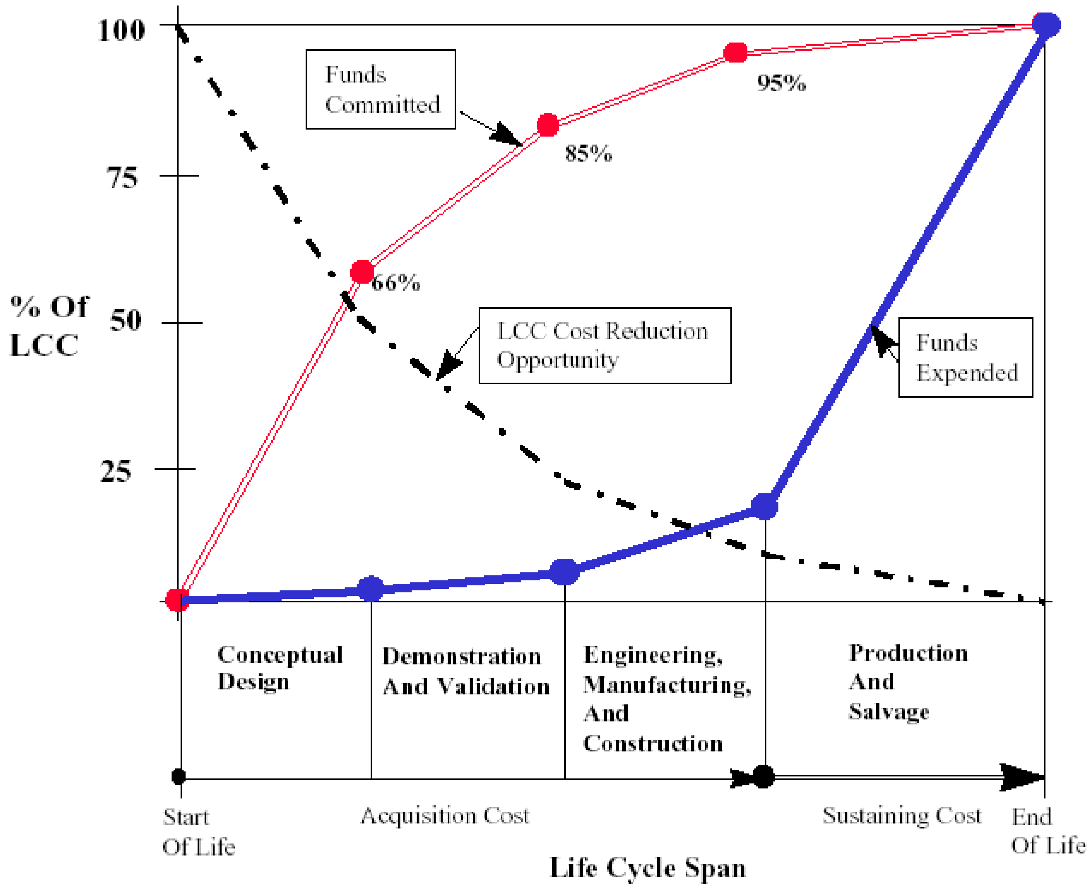

Figure 5. %LCC vs. Life Cycle Span [From Ref. 20]

In the past, the Army has relied on costly test-analyze-fix (i.e., reliability growth) programs in order to "grow" reliability until requirements were met. The decision to “design in” reliability depended on the individual program. There are, however, significant benefits to “designing in” reliability. Designing in reliability will achieve higher system reliability up-front, thus reducing unforeseen and costly failures during later phases in a program. Highly reliable components will significantly reduce a system's O&S costs and, thus, reduce the expensive process of reliability growth and the resulting project delay costs. It is crucial to emphasize, early on, the use of proper design tools and activities to “build in” reliability up-front, rather than relying on extensive “back end” testing and validation. [Ref. 21]

In a briefing on 22 February, 2001, Tom Edwards, Deputy to Commanding General Combined Arms Support Command (CASCOM), told the International Society of Logistics that reliability can be significantly improved by focusing on two main areas: 1) designing in reliability up-front, and 2) validating that we have reliable systems and components. This highlights the concept that reliability can be significantly improved by design early in the development process.

If a fielded weapon system is to have a high system readiness objective—either operational availability or probability of mission success—it must have high reliability. It generally is understood that to have a high level of readiness, one must have a reliable system. [Ref. 8] For a system to be reliable in the field, it must have good inherent design reliability that starts with the original design concept and continues throughout the development of the design. To reduce the risk of creating an unreliable system, the design should be required to follow certain reliability and maintainability practices and guidelines. It is essential that these practices and guidelines begin early in the design concept because poor or marginal reliability is often difficult to detect before the design effort is completed. The following section presents the benefits of using highly reliable parts, materials, and processes to achieve a high inherent reliability.

G. USING A PM&P PROGRAM TO "DESIGN-IN" RELIABILITY

Simply stated, highly reliable parts, materials, and processes are the building blocks of a highly reliable weapon system. While the system design approach is largely responsible for the weapon system's functional performance, the PM&P Program approach is responsible for a large part of the weapon system's reliability performance. Therefore, to insure that the reliability performance is being met, one has to evaluate the PM&P Program requirements, their implementation and verification, and the requirements' translation to the lowest part, material and process applied in the system.

The goal of a PM&P Program is the selection of parts, materials, and processes that can withstand the manufacturing environment and reliably perform the needed function for the design life of the product in the intended environment. Selection involves designing with parts and materials that have known reliability, superior life, durability, and corrosion resistance. Application involves using a PM&P Program to ensure that field environment stresses are less than the parts' and materials' strengths. Individual part, material, and process selection criteria and a PM&P Program should be used in the preliminary design to ensure that designers are provided preferred parts selection lists before design begins and that they continue to use only approved parts, materials, and processes in the system design. Examples of the adverse effects from designing without a PM&P Program include unknown failure mechanisms, inappropriate corrective actions, inappropriate design rules, low system reliability, etc. [Ref. 6]

The following case of microcircuits in a tactical missile offers an example of how a PM&P Program affects system-level cost and reliability. Suppose that the cost of the missile is $100,000, and the missile contains 70 microcircuits, each of which can cause a mission-critical failure. If 2000 missiles are produced, then there will be a total of 140,000 microcircuits. Now further assume that each microcircuit has 0.9989 reliability, and the reliability is allocated serially (as in Figure 2). This means that, on average, there will be 148 failed missiles and a lost value of $14,800,000. Now assume that there is a reliability test that can ensure 100 percent reliability and that this test will be performed on each lot of microcircuits at $12,000/lot. The total cost of the test would be $924,000 (with tests for seven additional lots). The lost value exceeds the test cost by ~16:1 and would likely justify the test cost to avoid the losses. This, of course, ignores the potentially life-threatening consequences of a tactical missile failure. [Ref. 22]

H. FORMER AND CURRENT DOD PM&P PROGRAM POLICIES AND GUIDANCE

The PM&P program is founded on DoD 4120.24-M *Defense Standardization Program Policies and Procedures*, which establishes the current policies and procedures to achieve the objectives required by 10 U.S.C.2451-2457, DoD Directive 5000.1, and DoD 5000.2-R. Under the DoD's performance-based acquisition policies, it is primarily the contractor's responsibility to recommend the use of materials, parts, components, and other items needed to meet performance requirements and satisfy other program elements, such as parts management and logistics support. Paragraph C3.2.4 of DoD 4120.24-M contains the following mandatory requirement:

> Program offices shall ensure that a parts management process is used to reduce the proliferation of parts and associated documentation and promote the use of parts with acceptable performance, quality, and reliability. [Ref. 23]

Prior to acquisition reform, detailed parts control program requirements for use on newly designed and/or modified equipment were typically invoked in contracts through Task 207 of MIL-STD-785. Task 207 required the establishment of a parts control program in accordance with MIL-STD-965. Figure 6 illustrates the relationship of MIL-STD-965 to MIL-STD-785 and other parts and material specifications. One of the provisions of MIL-STD-965 required contractors to submit parts lists to the Government for approval. Another provision was a part selection order of preference, in which military specification parts were considered first, and commercial parts could be considered only when no military part was available.

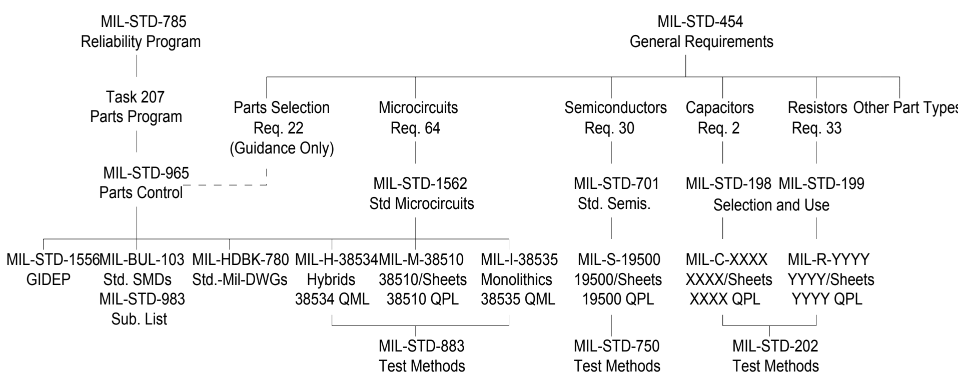

Figure 6. Reliability Design/Parts Application Specifications Prior to Acquisition Reform [From Ref. 24]

In order to be consistent with acquisition reform initiatives, MIL-STD-965 was converted to MIL-HDBK-965 in September 1996. In October 2000, MIL-HDBK-512 was released, and MIL-HDBK-965 was cancelled. MIL-HDBK-512 now provides the current guidance (guidance *only*— if it is cited as a requirement, the contractor does not have to comply) for implementing an effective parts management program on

DoD/Industry acquisitions. MIL-HDBK-512 supports the acquisition strategies and systems engineering practices of DoD 4120.24-M and DoD 5000.2-R. It also provides performance-based parts management process guidance, including the objective to enhance the reliability of end-item performance. MIL-HDBK-512 no longer requires contractors to submit parts to the Government for approval; nor does it require the preference of military specification parts over commercial parts. The management elements of MIL-HDBK-512 include: [Ref. 7]

1. Parts selection baseline. This is a parts selection list or database that should be maintained in order to give to designers and subcontractors the list of preferred parts and materials.
2. Parts selection and authorization process. These are the procedures for authorizing new parts to the preferred parts selection list. The procedures will identify the IPT or organization responsible for authorizing parts for use and the structure and membership of the IPT. The procedures will also include criteria used to ensure suitability of parts intended for use in the required application; order of preference used in considering new parts, and procedures for notifying associated disciplines (inventory, purchasing, quality assurance) in case authorization of a new part should be included.
3. Obsolescence management. This includes procedures for obsolescence management, which include proactive obsolescence forecasting for applicable part types (e.g., microcircuits) and plans for reacting and achieving solutions to obsolescence impacts as they occur and affect the program.
4. Subcontractor management. This element addresses contractor procedures for establishing and maintaining subcontractor IPT participation to ensure satisfaction of the PM&P Program objectives.
5. Part and supplier quality. This management element provides the requirements for assessing part suppliers and part quality, such as statistical process control data, audits, past performance, etc.
6. Part-level documentation requirements. Part-level documentation procedures need to be consistent with both the program's logistic strategies and its need for

performance and re-procurement documentation at the intended level of logistic support.

7. Substitute and alternate part procedures. This section addresses the process for the management and documentation of parts, other than those on an as-built or as-designed parts list. The program needs to be consistent with the intent and application of other disciplines (e.g., reliability, configuration management, quality, logistics, etc.).

8. Customer-contractor teaming. This part of the management plan addresses how customer teaming is provided so that process insight and program verification (i.e., IPT participation, technical interchange meetings, as-built, and other parts lists) are allowed.

I. COMMERCIAL PM&P PROGRAM PRACTICES

The American Institute of Aeronautics and Astronautics (AIAA) has established AIAA R-100 [Ref. 25], a document that is a collection of recommended practices for managing parts and materials. The AIAA standard establishes a management approach that is consistent with the current business environment. The document strategy is to manage risk up-front by selecting the right part for the intent application.

The standard emphasizes that a PM&P Program will deal pro-actively with parts and materials management issues and provide guidance for developing comprehensive strategies to manage cost and schedule risk via an IPT process. Figure 7 depicts the IPT process. The design process includes design margins, life cycle cost, technology insertion strategy, technical support, parts selection, and validation, all of which are addressed concurrently rather than sequentially. [Ref. 25]

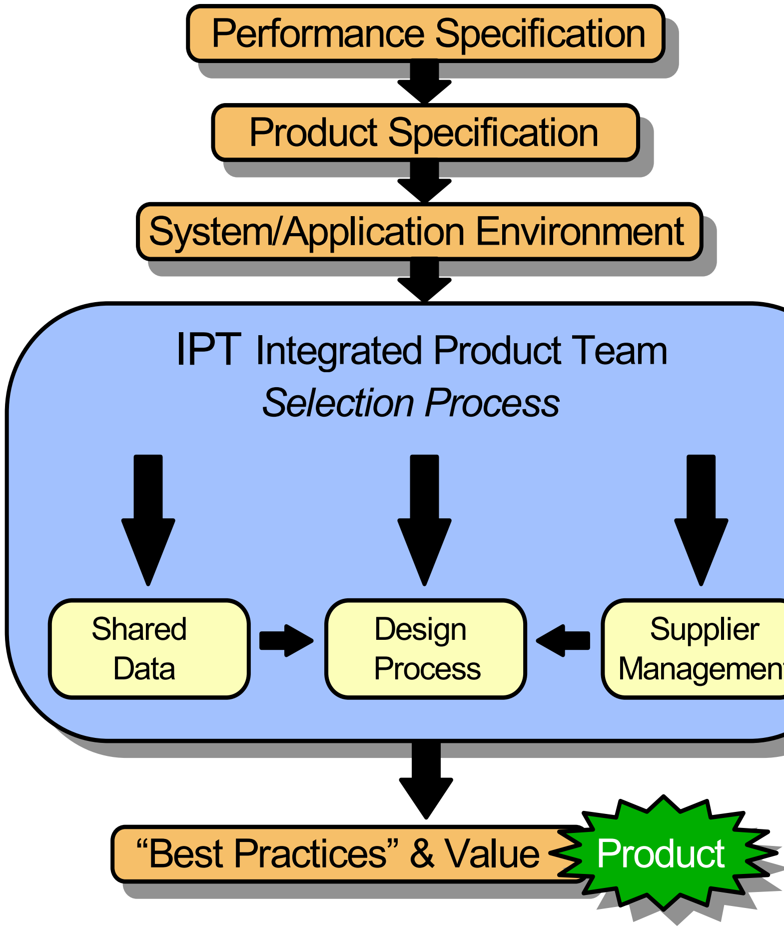

Figure 7. PM&P Management IPT Overview [From Ref. 25]

AIAA R-100 also establishes a design process. The flow diagram (Figure 7) illustrates that the interrelationships between the critical key elements of AIAA R-100 must be addressed concurrently to achieve the "best practice" selection of parts, materials, and documentation required for the design. Figure 8 is important because it shows not only the key elements that must be considered, but also that the objective of this design process is to evaluate inputs from all the key elements concurrently and to then select the parts and materials that satisfy the product requirements. Figure 8 is helpful to the DoD because it demonstrates that there is a commercial "best practice" document with a parts and materials design approach.

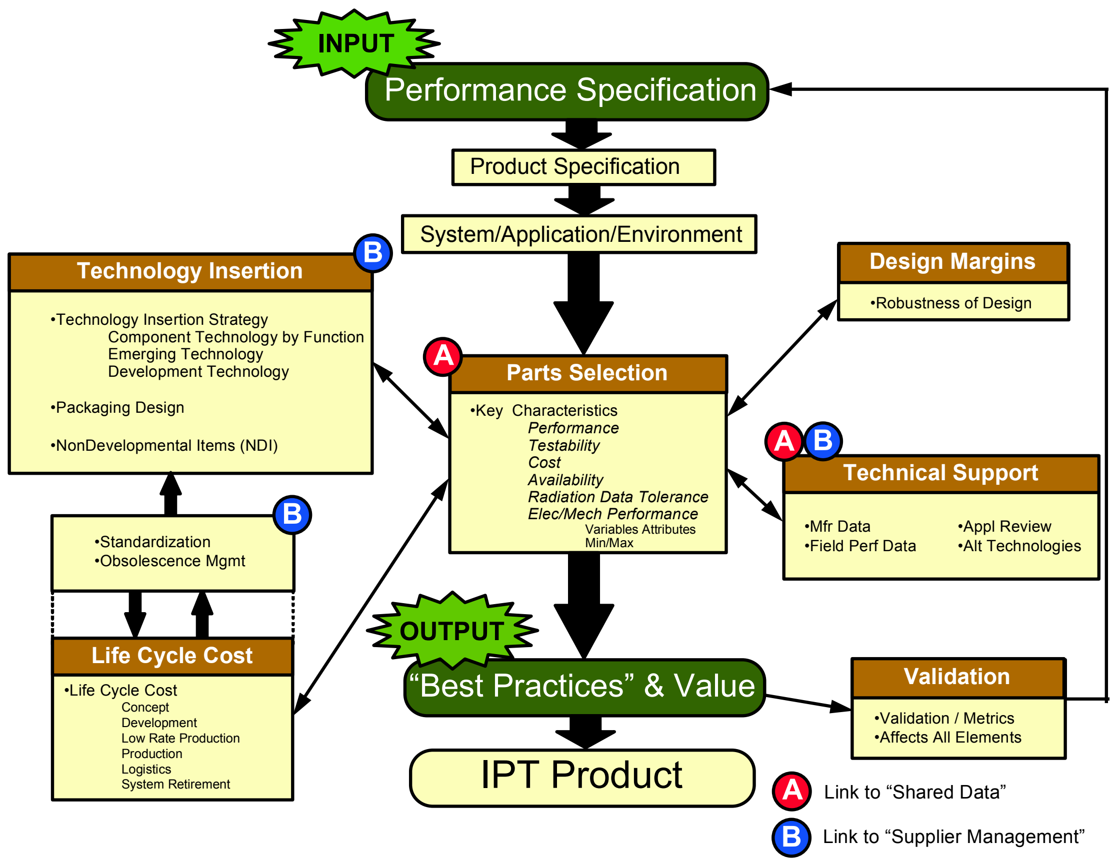

Figure 8. Commercial Best Practice Part Design Process [From Ref. 25]

J. SYSTEM- LEVEL RELIABILITY AND ITS IMPACT ON THE PM&P PROGRAM

Section D mentioned some of the impacts of selecting a flawed system-level reliability requirement. The impacts of this requirement are far-reaching, even down to the individual part level. Once the reliability requirement has been established, it will be allocated among the various subsystems, units, assemblies, and so on. For a system with a high reliability requirement, this means that the parts that make up the system will need to have even higher reliability.

For example, consider a system requiring 90 percent reliability. If the system were modeled with six components, each component would require a reliability of greater than 98 percent, if evenly allocated. At this high reliability level, the system becomes very sensitive to even one component not meeting its allocation

An example of the effect at the part level is the U.S. Army JAVELIN Missile. The guidance electronics circuit assemblies have a reliability allocation of about 99 percent, which includes about 120 microcircuits and semiconductors. Therefore, even if everything else is perfect (no solder joint, printed wiring board, or passive part failures), each microcircuit's and semiconductor's part reliability must exceed 99.99 percent. [Ref. 22] Now consider a system such as an airplane or helicopter, which has thousands instead of hundreds of such parts. Part reliability must be higher than system reliability, and even much higher depending on the number of parts; and failure to meet allocation on even one part would reduce the overall system reliability. The system-level reliability requirement is critical because once it gets allocated to the lower levels, it can easily drive the design and test at the lower levels of assembly (such as the individual piece parts) to unreasonable levels.

K. CHAPTER SUMMARY

In this chapter, the researcher described, first, the current reliability trend in the Army and, then, the PM&P Program. Background on how a reliability requirement is established on a weapon system included the origination of the requirement, how it is allocated, and the impact of establishing a flawed requirement. The relationship of reliability to logistics and life cycle costs was demonstrated. The benefit of "designing in" reliability was explained, along with the impact that system-level reliability can have on the individual parts and materials. The chapter covered former and current DoD policies and guidance, as well as commercial PM&P initiatives.

III. DATA

A. INTRODUCTION

This chapter identifies and discusses a variety of issues, common practices, concerns, and real-world experiences of subject matter experts (SMEs) who work on PM&P Programs. Data are presented from SMEs who work on programs that include missiles, aircraft, and space systems in various stages of development. The data were gathered through telephone interviews, using questions based on the literature review and the background research on PM&P Programs described in Chapter II. The questions were designed to draw out the experiences and practices of each SME on managing PM&P Programs.

This chapter is organized as follows: first, it discusses the general methodology and the process used to conduct the interviews; second, the chapter presents the interview question responses, grouped by common themes, and, where appropriate, provides them in tabular form; and, finally, it presents conclusions. Note that, with the exception of the definitions in Table 3, the source for the tables found in this chapter is the author, who based them on responses to the interviews.

B. METHODOLOGY

1. Overview

This thesis focuses on optimizing the use of highly reliable parts, materials, and processes—a key element in maximizing weapon system reliability. The objective is to develop a set of heuristics to assist future Program and Logistics Managers. The method for accomplishing this objective is to analyze the methods and beliefs of those who are considered subject matter experts (SMEs) in the field. Analysis of the tactics and strategies that can be used to maximize the inherent reliabilities of system components will not only help future Program and Logistics Managers, but will also assist the DoD in achieving reliability goals that remain elusive. Since the primary research question addresses "what" tactics and strategies can be used, the best way to answer the question may be through the use of in-depth cases. However, since in-depth cases were not practical for this thesis due to resource constraints, telephone interviews with SMEs, the individuals responsible for implementing the PM&P Program, were conducted instead. [Ref. 26] The purpose of the interviews was to gather data in order to identify common themes.

2. Development of Interview Questions

The interview questions evolved from the secondary research questions. The questions and their relationship to the research questions are depicted in the following matrix. (Table 1)

Secondary Research Questions	Related Interview Questions
1. What technology, tools, and techniques are available to ensure the proper selection of reliable parts and materials?	a. What design tools can be employed to ensure that reliability is "built in" early in the design of a weapons system?
	b. What methodologies and techniques are used to determine parts, materials, and processes compliance?
	c. What methodologies and techniques have succeeded, and do you have any examples?
	d. What methodologies and techniques have not succeeded, and do you have any examples?
2. How has acquisition reform changed the way a PM&P Program is managed?	a. How was a PM&P Program managed prior to acquisition reform?
	b. How did acquisition reform change the way the PM&P Program is managed?
	c. How did PM&P Program risks increase or decrease with acquisition reform?
3. To what extent does commercial industry differ in its approach to part and material selection, and can the Military leverage these best practices to improve performance in military systems?	a. What methodologies and techniques does commercial industry use to manage the PM&P Program?
	b. What commercial industry techniques can DoD adopt?
4. How can a Program and Logistics Manager mitigate part and material risks?	a. What are the top three things a Program Manager can do to mitigate part, material, and process risk and maximize reliability in the design?
	b. How much and what kind of input does the PM get from the Logistics Manager on PM&P Program issues?
	c. Could the level of input be improved? Why or why not?
	d. If there is input from the Logistics Manager, is it useful?
	e. Are there any examples (good or bad) of this interaction?

Table 1. Relationship Between Research and Interview Questions

3. Choice of Study Subjects

Interview subjects were chosen based on convenience sampling. Although this technique may not be representative of the population as a whole, the information can still provide some significant insights and be a good source of data. [Ref. 27] Interviews were conducted with individuals from the Army (U.S. Army Aviation and Missile Command), Navy (Naval Air Systems Command), and Air Force (Space & Missile Systems Center) and with contractors with whom they interface. Due to their high cost and the safety-related nature of their application, these particular systems require a high degree of reliability. Each SME has a minimum of ten years' experience working with PM&P Programs on military weapon systems. A total of 11 interviews were conducted. This base of subject matter experts should provide a fairly representative cross-section of experiences in utilizing highly reliable parts, materials, and processes in weapon systems.

4. Interviews

Interview questions were distributed to each SME via email, along with information regarding the objectives of the interview. This email was then followed up with a telephone interview. Since the interview subjects were located throughout the country, in-person interviews would have been neither cost-effective nor timely. [Ref. 26] In order to ensure that the data were valid, the interview subjects had full editorial control. If the answers were recorded incorrectly, the SME was given full opportunity to make corrections, or else the data were not used.

Questions were written in a manner to avoid justifications—that is, they asked "how" instead of "why." Leading questions and "yes or no" questions were avoided, as well. The goal was to get the subjects to express their ideas and thoughts about the issues. Table 2 summarizes the steps used in conducting the study.

1.	Identify and analyze the primary research question.
2.	Conduct a review of reliability and PM&P Program literature.
3.	Develop interview questions for subjects to obtain data to answer primary and secondary research questions.
4.	Conduct a review of personnel who have extensive experience with PM&P Programs and issues.
5.	Arrange for and conduct telephone interviews with subjects.
6.	Analyze subjects' responses for common issues.
7.	Compare subjects' responses.
8.	Develop generalizations and summarize data.
9.	Develop a set of critical strategies and tools to aid future PMs and LMs.

Table 2. Summary of Methodology

C. TECHNOLOGY, TOOLS, AND TECHNIQUES

The first group of questions focused on the technology tools and techniques that are used to select and control the parts, materials, and processes; how compliance is verified; and what methods were successful and unsuccessful. The first question asked about the design tools that can be employed to ensure that reliability is "built in" early in the design of a weapons system. The SMEs' answers and their definitions are shown in the Table 3 below.

Reliability Prediction Analysis - is simply the analysis of parts and components in an effort to predict the rate at which an item will fail. A reliability prediction is one of the most common forms of reliability analyses.
Circuit Tolerance Analysis – is a technique, which, by accounting for component variability, determines circuit performance under a worst-case scenario, i.e., under extreme environmental or operating conditions. This analysis is particularly cost-effective in safety-critical applications and for products expected to operate in severe environments.
Sneak Circuit Analysis – detects design flaws that escape reliability testing and impacts system performance by activating unwanted functions or impeding desired functions. It is crucial that sneak circuits are found as early as possible. Failure to do so can lead to costly late redesign or safety-related failures.
Physics of Failure (PoF) Tools – is an approach that uses knowledge of root-cause failure processes to prevent product failures through robust design and manufacturing practices. The PoF approach proactively incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures, and electronics technologies. The PoF approach encourages innovative, cost-effective design through the use of realistic reliability assessment.
Part Derating – is the practice of limiting electrical, thermal and mechanical stresses on parts to levels below their specified ratings. If a part or material is expected to perform reliably, it must incorporate a conservative design approach using derating.
Government Industry Data Exchange Program (GIDEP) - is a cooperative activity between Government and industry that reduces or eliminates expenditures of resources by sharing technical information essential during research, design, development, production and operational phases of the life cycle of systems, facilities and equipment. Proper utilization of GIDEP data can improve the reliability of systems and components during the acquisition and logistics phases of the life cycle.
Prohibited Parts List – is a listing of parts deemed unacceptable by the PMB for use in a company's products because of cost, quality, safety, etc.

Failure Mode, Effects and Criticality Analysis (FMECA)—or simply FMEA—identifies potential design weaknesses through systematic analysis of the probable ways (failure modes) that a component or equipment could fail. It is a disciplined technique that focuses the development of products and processes on prioritized actions to reduce the risk of product field failures, and it documents those actions and the review process.
Fault Tree Analysis – is a deductive, top-down method of analyzing system design and performance. It involves specifying a top event to analyze (such as a fire), followed by identifying all of the associated elements in the system that could cause that top event to occur.
Part and Material Selection List - is a part and material listing preferred for use in equipment design, which often contains descriptions, attributes, or application information.
Product Change Control – consists of process and procedures that manage how changes are incorporated into a product. Product Change Control is a part of overall configuration management and uses review and release processes to enforce compliance with enterprise change policies.
Finite Element Analysis - is the method of simulating a physical part or assembly's behavior by building a model of the geometry, dividing it up into connected elements, applying loads and constraints, and then calculating deflections and stresses.
Failure Reporting and Corrective Action System (FRACAS) - is defined as a closed-loop process for identifying and tracking root failure causes and subsequently determining, implementing and verifying an effective corrective action to eliminate their reoccurrence. The FRACAS accumulates failure, analysis and corrective action information to assess progress in eliminating hardware, software and process-related failure modes and mechanisms.
Circuit simulation tools - simulates and verifies a design for logic and testability functions, timing behavior, and accuracy to other representations of the design (behavioral-level, discrete breadboard-level, etc.), and performance in the target system.
Design Verification Test (DVT) - involves detailed tests to verify conformity to all applicable interface standards, as well as all vendor-specific specifications and diagnostic commands. Performed to validate designs, DVT is extremely rigorous and often subjects the product to heat/cool, electrostatic, and EMI/RFI testing.

Table 3. Design Tools [From Ref. 28]

The purpose of the second question was to discover the methods and techniques used to determine parts, materials, and processes compliance. Table 4 provides a list of the responses.

Receiving Inspection
Qualification Testing
Environmental Stress Screening
Reliability Growth Testing
Process Controls
Reliability Predictions
Prohibited Parts List
Evaluation of Contractor PM&P Program
Data Review
Surveys and Audits
Destruct Physical Analysis (DPA)
Communication

Table 4. Techniques used to determine compliance.

The third question dealt with the methods and techniques that succeeded. This section groups the responses into the following categories: (a) Testing, (b) Communications, and (c) Data analysis. These categories were based upon how the interviewees addressed the topic. Excerpts from the interviews are provided below.

a. Testing

The following interview excerpts deal with the topic of testing.

> When in doubt, test the parts. Example: on Program XXXX, the supplier qualification data for a SCR-Diode module showed the piece part qualification had been done on a sample size of only ten pieces, and Autoclave had not been done at all. We did a full qualification test per the requirements, with sample size of 50 for all tests except life test, which was done on 80 parts. Ten percent of the modules failed temperature cycling and autoclave due to what appears at this time to be an inherent design problem. The sample size of ten pieces in the supplier qualification in only one of the tests failing was not adequate to identify this problem.

> Plastic encapsulated microcircuit qualification testing and unit qualification testing [are important] because [they] screen out weak suppliers.

> [We performed] plastic encapsulated microcircuit sequential testing; this was example of [an] independent test that allowed programs to separate the inconsistent vendors from the consistent ones.

b. Communications

The following excerpts discuss communication.

> Require a PM&P Program that clearly outlines the procedures necessary to have in place to ensure the use of quality components that will meet the

overall system performance requirements. There needs to be an expert in this field as part of the team that develops the plan and should be involved with any modifications to the plan. There is a company that has recently developed a plan that covers all three services and was put together with input from representatives of all three services. It is up to each program to ensure the plan is being implemented properly.

We only get data when we fail. It's difficult to tell what works; we have tracking of what does not work. Most times, the problem is the contractor changing things and not telling the prime. Adherence to processes and communications is the key.

Supplier Surveys and Audits are especially successful. If nothing else, they give the Program Office and contractor personnel a chance to meet face-to-face to discuss issues and problems.

We are also having success with conducting supplier-management surveys and audits. It's been very successful at getting insight into what the contractor does, especially for keeping track of process changes.

c. Data Analysis

The following excerpts have to do with data analysis.

IPT working groups are needed to analyze parts and materials, methodically reviewing parts against the application requirements.

You basically have to know if the part or material is right for the application and if it fits the mission profile.

Proactive Integrated Product Teams (IPTs) are one of the best vehicles to ensure product performance, reliability and repeatability. This method ensures all parties are addressing these issues and are staying connected. However, this only works when all functionals participate and coordinate their efforts.

To ensure reliability, you will have to get down to the supplier and get into his processes to ensure piece part reliability.

The fourth question dealt with the methodologies and techniques that have not succeeded. The responses to this question were interesting because most of the answers had nothing to do with tools and techniques. Instead, most of the responses were about communication and the lack thereof. This section groups the responses into the following categories: (1) Communications and (2) Design Process. Excerpts from the interviews are listed below.

d. Communications

The following excerpts regard communication.

> That's tough because a lot here can depend on how you approach you counterpart. An aggressive approach usually yields a level of distrust and standoffness.
>
> Contractor Management of their own PM&P without Government oversight [is needed].
>
> We get into trouble when we buy a "black box" and don't pay attention to what PM&P is in it. An example is the use of pure tin. For most part types it's not allowed due to tin whisker growth. On one program, the subcontractor had tin in his black box, and he did not inform the prime contractor. The prime also did not verify the materials in the black box. The box failed and caused the failure of a high-profile, high-cost missile test.
>
> [There is a] lack of concurrent engineering (the IPPD process is not always rigorously applied).
>
> [We] rely on contractors to provide a system that meets a performance requirement without insight.
>
> I know of no problems with the tools or techniques. There was a problem with the subcontractors. They were making changes to processes without telling the prime contractor.

e. Design Process

The following responses address the design process.

> Destructive Physical Analysis (DPA), when not accompanied by a comprehensive PoF model, may not be adequate . . . to identify potential problems in parts.
>
> The most important thing is paying attention to detail.
>
> The most prominent practice that comes to mind is when the contractor uses the "design as you go" methodology. The design NEVER gets locked down, and engineers are standing behind the operators changing layout and components as the CCAs are fabricated. This often results in shorts, opens, and numerous jumper wires and wrong parts.

> Not using the design techniques I mentioned before.
>
> Contamination of plastic encapsulated microcircuits that will cause a latent failure, intermittent problem, or system failure. The soldering process (part to board, usually from a poor-cleaning process) usually causes this.

D. ACQUISITION REFORM

The second series of interview questions focused on the effects of acquisition reform on PM&P Programs and how PM&P Program risks increased or decreased with acquisition reform. The first question inquired how a PM&P Program was managed prior to acquisition reform. There was almost complete agreement in the responses to this question. All of the subjects responded that strict control was established through military specifications and standards that were contractually required. Below are the responses.

> MIL-STD-965 was used. Parts needed to be selected off a list, and if it was not on the list, a "Non-standard Part Request" was submitted to the Government. Also, there was a full level-III technical data package, and all the reliability tasks of MIL-STD-785 were required.
>
> Use of MIL-STD-965. Use of military specification parts/established reliability parts was the first order of selection. Standardization was emphasized.
>
> MIL-STD-965. Part Engineers would review the final parts selected, for compliance to standard requirements at the end of the line.
>
> Control, Control, Control.
>
> Contractors were required to adhere to military specifications and standards as required in their contracts.
>
> Design guidance called MIL-STD-11991 and MIL-STD-454 were used. It specified what PM&P to use and what not to use. MIL-STD-965 was used for standardization; it also required the use of military specification parts. It did not allow commercial parts. There were a lot of data requirements. Data would have to be sent in to the Government for review and approval as official data submittals.
>
> Control of a level-III TDP allowed for more Government control/insight into the parts used.

MIL-STD-965 was required.

[The] MIL-STD-965 requirement was invoked in the contract. This required the contractor to submit all parts, and some materials, to be used in design, (except those parts contained in the Government-furnished baselines or those previously approved by contract), for approval. The problem for the contractor was the time it took to receive a part approval, which included subcontractor part submission to the prime contractor and then prime contractor submission to the Government (not done electronically).

We used two documents, MIL-STD-1546 and MIL-STD-1547. MIL-1546 was like MIL-STD-965, but more stringent. MIL-STD-1547 was more technical; it specified the exact screens, tests, PDA, lot size, etc. These two documents told contractors how to manage the PM&P Program. Contractors were required to have a PM&P Program, and they had to have a PM&P Control Board.

All the typical quality and reliability Military Specifications and Standards were levied in the contract. The contractor was required to adhere to the military specifications and standards as required in the contract. This included requirements such as MIL-E-11991, MIL-STD-965, MIL-STD-785, MIL-STD-1629, MIL-HDBK-189, and MIL-HDBK-781.

The second question tried to ascertain how acquisition reform changed the way the PM&P Process is managed. All of the responses reflected the fact that military specifications and standards could no longer be required. The responses are shown below.

It shifted from an imposition of standards to a process whereby the contractors describe their processes and procedures. If these processes and procedures do not meet the goals of the PM&P Program, the differences are negotiated to resolution.

[We] cannot use MIL-STD-11991 anymore. Contractors now have to each create their own PM&P design guidance. Contractors still have to get data to make decisions and some still submit data, but it is on a voluntary basis now. If a teaming arrangement is in place, most data is (sic) obtained informally, but sometimes travel is required to go look at it because they won't send it out.

Parts and materials engineers must become more knowledgeable and must be multi-disciplined. One of the most important aspects of parts engineering now is to be a part of the early component-selection process.

Parts Engineering has become an up-front activity, where in the past, under MIL-STD-965, it had become an end-of-the-line activity.

With acquisition reform, the Government can somewhat control the process in which parts and materials are chosen and tested, but there is not the control down to the piece part level that was there before.

Less documentation required, screening and qualification levels lowered or non-existent, allowance of plastic encapsulated microcircuits in military systems, significant increase in parts obsolescence, and dependence on product change notices.

Too liberal. The response was to throw away everything we knew and proceed blindly. The move to acquisition reform was not well thought out, and companies reacted blindly to strip parts support from design activities

It changed from a MIL-STD-965 requirement to a performance-based statement of work type of requirement (examples contained in MIL-HDBK-512). The contractor would respond to the SOW requirement with his internal part management process. NAVAIR would review the process to insure that all of the standardization, reliability, and supportability issues were addressed. To ensure compliance, NAVAIR would have to maintain insight through access to the contractor's part database.

From a contractual standpoint, there were no more "how to" requirements; neither were there any more technical process requirements. The underlying philosophy is that the contractors have their own PM&P Program. There is some up-front assessment prior to contract award, but there is no longer a standard process for all programs. Also, the contractor has much more flexibility to express part-level test requirements.

Military specifications for PM&P Program management were no longer imposed. All the plans and practices that were established in the military specifications were gone, and now each contractor had to manage and/or develop their own PM&P requirements. Use of commercial parts was emphasized.

The contractor is now given a performance specification in which he is required to provide hardware that complies with the performance requirements as stated in the contract. The contractor is allowed to do whatever is necessary to ensure the hardware meets the requirements stated in the contract.

> By tailoring contractual language to detail performance requirements in such a way that the contractor cannot claim that we are, in fact, telling him "how to" build our product.

The third question tried to determine if risks relative to the PM&P Program increased or decreased with acquisition reform. There was almost complete agreement that the risks had increased. Below are the responses. The lone exception was an individual who worked on a weapon system that was still using military specification and standards requirements. The program had negotiated an agreement with the contractor to keep using the requirements, and that subject stated that there was no change in risk. The responses are listed below.

> Risks are especially high in organizations where Parts Engineers are not knowledgeable and are not involved in the component selection process.
>
> Risk has increased, but it is dependent on the Project and the people working in the project. Communication is the key . . ..
>
> Risk increased due to [the] answer above, but risk also decreased due to use of IPPD process (better coordination between disciplines, more tailoring of selected capabilities to application requirements).
>
> The risks increased. We relinquished control (as required by no contract requirements), and the risks increased.
>
> Risk has increased because no standard methodology of parts management is in place.
>
> In my opinion, risk has increased significantly. The Government tried to balance cost and resources and it did not work. The contractor needed to modify processes to lower the bid price, so they streamlined the specifications and standards, along with personnel and processes.
>
> Risks to the Government increased. This was due to the fact that we only knew what the contractor did, as far as part decisions, after the fact, and in some cases, due to a lack of personnel, not at all.
>
> Risk has not increased or decreased at all on the program [where] I work. We still use all the military reliability requirements.
>
> Risk has increased, but it is dependent on the Program Office and the people working there. Communication is the key; if it is good, the risk is

lower, [and] if it is bad, then risk has increased due to the lack of oversight and inadequate peer review.

Risks increase for contractors who are not willing to negotiate towards the goals of the PM&P Program; the risks decrease for contractors who are willing to negotiate in good faith in order to deliver quality hardware.

Definitely much more risk. It is next to impossible to get a contractor to do anything outside of their normal operating procedures (which are usually under the auspices of "best commercial practices") without hard contractual requirements to back them up.

E. COMMERCIAL INDUSTRY

The third series of interview questions focused on the methodologies and techniques that commercial industry uses to manage parts, materials, and processes and what commercial industry techniques, if any, the DoD could adopt. The first question asked about the methodologies and techniques commercial industry uses to manage parts, materials, and processes. These are the responses:

They do not really do anything differently. They have more of the ability to start research or perform special testing (if necessary) on new materials. A lot of times, commercial industry can be more tolerant of failures (depending on market impact), such as poor production yield.

I cannot comment, as I have no experience with commercial OEMs.

Not sure.

They depend on Process Change Notices (PCNs) from part suppliers. They also do more first-article qualification at the part level.

They are selective in suppliers they deal with and they use "agreements" to control proliferation. They also manage their suppliers much more efficiently than military.

If commercial industry has processes, they would closely resemble those of the Defense Contractors. Defense Contractors only developed their processes because of MIL-STD-965.

Commercial companies certainly do PM&P Management, but it is a totally different business. The make use of strong incentives and high volume production. The incentive is the opportunity for follow-on business. The big difference between commercial and military is that commercial industry uses high volume and [a] low number of part types. The military is just the opposite. This gives the commercial industry a lot more leverage.

Some companies are trying to develop their own design guidance. The problem is that it is high-order and not detailed. However, some good documents do exist for guidance, including the AIAA R-100, SAE R&M 100, AEC QS9000 documents, and the Stack International documents (these document are based on the old military specification and standards).

In a general sense, they each have company standard processes that they use. But each company and each division within a large company all use their own peculiar process. Some don't even manage PM&P. Some still use military specifications, but most have abandoned due to cost.

When it is to their financial advantage, the contractors will adhere to select guidelines contained in the PMP. It has been my experience, however, that they will always do what is the fastest, cheapest and easiest process.

I will take a pass on this one; I don't have insight into commercial processes.

The purpose of the second question was to see if the respondents thought that DoD could adopt any commercial industry techniques. As might be expected after reading the responses to the above question, the subjects did not think that many commercial techniques could be utilized. Five either did not know of any commercial techniques or could not think of any that DoD could use. Below are the responses of those who did have an answer.

Concurrent engineering and IPPD, which we are using.

Contractors have the ability to quickly obtain expertise from experts when they have PM&P issues. There are a number of consulting firms that will provide this service. However, we have teamed with most of our contractors to create basic methodologies based upon a combination of our lessons learned and their lessons learned information. I don't know; I don't see a lot of things different. We do try to utilize any industry document that we feel is applicable to missile systems—e.g., AEC, EIA, Stack international, etc. Also within other Government agencies—for example, the Department of Energy has just forwarded us a preliminary design guide that one of their subcontractors has developed for the nuclear people.

In the past, DoD has not been willing to pay the upfront cost needed to set a "commercial" infrastructure. Too many rules and regulations. It's not politically correct. Until this "control" without payment idea is changed, it will be difficult to adopt the buyer/seller relationship, guaranteed procurements, standardized products and block upgrades.

None that I'm aware of.

It's difficult to say. The consumer product is very different from what the military requires. The military requires very robust, long lasting parts. The commercial world does not necessarily test parts, even though they guarantee parameters. The military requires actual testing and not just guarantees. It's also hard to leverage off the commercial world because they design to a different level. Some projects are doing "up-screening" to get parts that perform adequately.

This all depends on the DoD system. If the DoD is developing a system that is typical to the environments and lifespan of commercial hardware, then we can adopt many of the industry techniques. If, however, we are developing a system that is to be deployed in [a] very harsh military environment with fairly lengthy life cycles, then we need to be very careful what techniques we allow. We are currently allowing the use of certain test data from microcircuit manufacturers to provide confidence that the manufacturing process used is sufficient to produce quality components. In some cases, manufacturers do not provide sufficient data to warrant this, and further tests are needed to provide that confidence.

F. MITIGATING PM&P RISK

The fourth interview question was about things a Program Manager can do to mitigate part and material risks. The question asked the top three things a Program Manager can do to mitigate part, material, and process risk and maximize reliability in the design. The responses below list the interviewees' suggestions.

1) Recognize that they need to perform qualification testing at the part and material level; 2) require the contractor to implement a comprehensive FRACAS down to the part level; 3) monitor suppliers for changes to PM&P that would affect performance.

1) Plan for adequate funding in the reliability area and don't take it. Programs usually take money from test and reliability for other priorities; 2) Have project office personnel participate in all (or as many as possible) IPT meetings; 3) emphasize communication at all levels. Some programs keep too much information "close hold" and do not have adequate peer review with subject matter specialists.

1) Ensure that highly knowledgeable commercial component experts are involved in the early concept process and the early part selection process; 2) allocate funding for independent testing of piece parts, and let the Component Engineers know that there are no barriers to testing of parts where they feel it is required; 3) require that the entire part review for each part be documented; perform QC audits of the PM&P review process early in the Design, and periodically throughout the design process.

1) Develop a comprehensive PMP plan as early as possible in the system life cycle; 2) maintain support from PMP "experts" throughout the program; 3) make sure the performance spec has adequate requirements to enforce the PMP program.

1) Provide adequate budget for detailed part assessments; 2) enforce part test and qualification requirements; 3) use a piece part level FRACAS that requires root cause analysis down [to] the part level.

1) Establish the PMP rules and authority immediately after contract award; 2) empower the PMP organization to do its job within the boundaries outline by the first bullet; 3) support the PMP activities within the engineering design organization.

1) Write good contract requirements; 2) invoke a Parts Management Program (PMP) requirement in the contract; 3) assign a PM&P Program IPT lead to insure that all part technical issues, including "lessons learned," are addressed.

1) Know and understand your part and material application; 2) know and understand the inherent design of the parts and materials; 3) know your part and material suppliers.

1) [Have a] Parts Management Plan; 2) use and support effective Testing Techniques (part level, board level, DVT); 3) use adequate design tools.

1) He needs a PM&P Plan that includes testing at the part level; 2) need to perform construction analysis on parts to verify changes; 3) need a closed loop FRACAS to avoid long-term reliability problems.

1) Allow early part expert review of selection of parts and materials; 2) fund qualification testing of parts and materials; 3) fund root cause and corrective action of part failures early in design and during production.

G. INTERFACE WITH LOGISTICS

The last series of interview questions focused on the type and quality of input a PM gets from the LM on part, material, and process issues. The first question asked how much and what type of input the PM gets from the LM on part, material, and process issues. There was overwhelming consensus that there is little support from the LM. Below are the responses.

> Logistics does not do much up front.
>
> I work several programs, and I only know of one program that gets input from the LM; otherwise it is non-existent. The type of input usually revolves around supportability issues. Actually, what I am trying to say is I only have one program where the logistics people work closely with other engineers, such as this office, to provide the best advice to the PM. Usually logistics works largely independent of everyone else, it appears. All programs get input from logistics, but on other programs they don't always seem to work with other organizations.
>
> I cannot comment on this, as I have not interfaced with Logistics.
>
> Very little that I have seen.
>
> They provide very little input, only minimal input of field failure data and standardization.
>
> None that I am aware of.
>
> These questions are difficult to answer because generally there is not any input from the Logistics Manager.
>
> Don't know, our organization does not get much input from logistics.
>
> Logistics is not really involved.
>
> The space world does not do sustainment; once it's launched, that's it.
>
> Usually nothing.

The second question asked how the level of input could be improved, and why. Again there was an overwhelming consensus; this time, most respondents thought the level of support from the LM needs improvement. Below are the responses.

> Yes, they could provide the logistics impacts of the early design.
>
> Yes, it definitely could because when the LM understands the importance of reliability and when he provides good support and works with other functional support people, the PM gets the better recommendations.
>
> Yes, it would help with supportability type issues.
>
> Yes, he needs to be involved. He is the one that has all the lessons learned from the field. Education of the logistics people is a big issue.
>
> Yes, it could be improved, but it might be hard to get logistics involved. In the past, they have offered support on issues such as transportability.
>
> I cannot comment on this, as I have not interfaced with Logistics.
>
> Needs to be improved.
>
> Yes, they could provide better feedback at the part and material level from the field and depots.
>
> Yes, he needs to be a big part of this because obsolescence is such a big issue with short-life-cycle items like computer parts.
>
> I am not sure. Perhaps they could provide input into specification requirements.
>
> It is a matter of philosophy of the program. I believe with the level of integration and pin count density has lead the logisticians to stop at the LRU/CCA level (since a depot probably should not be performing piece part removal and replacement).

The third and fourth questions asked the respondents to say if the input from the LM is useful and to give examples (good or bad) of that input. The subjects typically did not answer these two questions because of the lack of contribution from the LM. In the rare times that the LM offered input, some thought it useful and some did not. Below are the responses regarding input from the LM.

> Not really. The logistics manager appears to be lacking the technical skills needed to impact the early design.
>
> Yes, very useful. Like I said before, I think it is most useful when the logistics works closely with reliability, engineering and other groups and

> the projects. The LM offered input on how the equipment would be used by the soldier in the field. After discussions with product assurance people and other engineering, it caused a design change that would not have otherwise been made.
>
> All feedback from Logistics is useful since it allows the PM to alter the design, if necessary, to account for issues seen in the field.
>
> Input is only minimally useful at the LRU or subsystem level.
>
> At my level of insight, typically no. When it comes to obsolescence, the length of time it takes the logistics community to determine what assets they are in need of, the window of opportunity has closed.

H. CONCLUSION

Eleven SMEs in the parts, materials, and processes functional area described their experiences working on weapon systems. The SMEs represented programs from the Army, Navy, and the Air Force. Each person discussed characteristics of the program or programs he works on. The responses were indicative of their personal experience in working on PM&P Programs. The next chapter contains an analysis of these data and an attempt to develop a set of heuristics to assist future Program and Logistics Managers.

IV. ANALYSIS

A. INTRODUCTION

This chapter analyzes the data presented in the previous chapter. The analysis is based on the interview responses of participating subjects and is structured around the same topics as in Chapter III. The analysis consists primarily of comparing the survey responses to one another, searching for common issues and identifying trends. The researcher uses this analysis to identify strategies and tactics for optimizing the use of highly reliable parts, materials, and processes in order to maximize system-inherent reliability in the life cycle.

B. CLASSIFYING INTERVIEW DATA

Analysis of the interview responses was conducted according to the classification scheme presented in Chapter III. The interview responses were organized in relation to the secondary research questions, and a comparison was made to yield trends and commonality. In general, the secondary research questions pertain to five categories: 1) the technology, tools, and techniques available to ensure the proper selection of reliable parts and materials; 2) the way in which acquisition reform has changed how a PM&P Program is managed; 3) the extent to which commercial industry differs in its approach to part and material selection; 4) how a Program Manager can mitigate part and material risks; and 5) how a Logistics Manager interfaces with the PM&P Program.

C. ANALYSIS OF KEY ISSUES

1. Technology, Tools, And Techniques

What enablers allow the selection and verification of highly reliable parts, materials, and processes? From the data gathered, there appear to be numerous tools and techniques that can be used to ensure that the design of a weapon system is maximized for reliability.

Table 3 of Chapter III listed and defined the technologies, tools, and techniques that were mentioned in the interviews. Table 5 below lists the six most frequently mentioned responses (mentioned by at least four of the subjects). Definitions of these tools are listed in Table 3, Chapter III.

Top Six Design Tools That Are Used To Ensure That Reliability Is "Built In" Early In The Design Of A Weapons System
Reliability Prediction Analysis
Circuit Tolerance Analysis
Sneak Circuit Analysis
Physics of Failure Tools
Part Derating
Government Industry Data Exchange Program

Table 5. Top Six Design Tools

Proven and/or disciplined design approaches are a critical factor in the reliability success of a product. The tools and techniques in Table 5 were identified in the interviews as most utilized by programs in weapon system design (part and material selection and control).

The four most frequently mentioned methodologies and techniques used to determine compliance are listed in Table 6. Interestingly, all but two of the interview subjects stated that some sort of testing was necessary to verify compliance. One even responded with, "Testing, testing, testing, (i.e., all types: board-level, part-level, independent testing, DVT, and special testing), all types and levels are important." The responses were a strong indicator that testing at all levels is critical to verify part and material compliance. All of the interviewees mentioned that either testing or some type of data review is necessary ensure compliance. Even the establishment of a PM&P Program was secondary to testing.

Top Four Methodologies And Techniques Used To Determine Part, Material, And Processes Compliance
Testing (i.e., Environmental Stress Screening, Qualification Testing, Design Verification Testing, Independent Testing)
Evaluation of Contractor PM&P Program
Data Analysis and Review
Surveys and Audits

Table 6. Top Four Verification Methods

The answers to the question about successful methodologies and techniques provided the common themes listed in Table 7. Adequate communication was the answer mentioned by most people. Everyone responding also said something about performing some type of testing or data review. There already is a recurring theme that testing needs to be part of a PM&P Program.

Successful Methodologies And Techniques
Communication through IPTs
Part and Material Testing.
Surveys and Audits

Table 7. Successful Methodologies and Techniques

The subject of methodologies and techniques that have not succeeded did not yield the type of answers expected. This was intended to be an assessment of the tools and techniques that were identified in Table 3 of Chapter III. Only one of the answers had something to do with tools and techniques; most of the responses were about communication and the lack thereof. Though unexpected, the answers were, nevertheless, consistent with the answers to the previous question. One interview subject stated that "the lack of concurrent engineering" stood out in his mind as the biggest issue.

Another response was that "communications is vital." Someone else said, "It depends on how you approach you counterpart. An aggressive approach yields a level of distrust." It was evident that all the respondents believe communication to be one of the more important aspects of a successful PM&P Program. In a separate discussion, one individual remarked:

> I do not believe there are any tools you can use to build in reliability. Select the right part from the right supplier based upon all the available data you have . . . to ensure reliability, you will have to get down to the supplier and get into his processes to ensure piece part reliability.

This and the other statements strongly imply that communication between all the parties involved is the most critical factor.

2. Acquisition Reform

This section analyzes the effects of acquisition reform on PM&P Programs. There was complete consensus about the way PM&P Programs were managed prior to acquisition reform. Consistent with the literature review, the common theme was that strict Government control was established through military specifications and standards. MIL-STD-965 was the prevailing document that compelled the use of a standard process. Along with the requirements of MIL-STD-965, one person said that "there were a lot of data requirements, and data would have to be sent to the Government for review and approval."

For changes after acquisition reform, there was universal agreement that military specifications and standards could no longer be used. This was also as expected from the literature review. Because of the change to performance-based contracting, the level of control enabled by military specifications and standards was no longer there. The focus shifted from controlling the design of the product to having insight into the contractor's processes. The answers also indicated an increased dependence on the ability to communicate. No longer could a program sit back and wait for data to be delivered. If a program wanted insight at the part and material level, personnel had to be proactive and get the information by participating in the IPT process. The result of not being able to use military specifications and standards can be grouped into three categories: 1) there is no longer one uniform process with strict Government control; 2) there is an inability to utilize the lessons-learned contained in the military specifications and standards; and 3) requirements had to be specified in performance-based terminology.

On the question of post-acquisition reform risk, there was an overwhelming consensus that acquisition reform had increased risk. All of the survey respondents were in complete agreement, except for one individual, who said that risk had not changed. His program had negotiated with the contractor to maintain the requirements that were in the cancelled military specification. Even without taking this into account, its obvious that acquisition reform is not held in high regard in the parts, materials, and processes arena. The most interesting part was that even the contractors who were interviewed also agreed that acquisition reform had increased risk. This is interesting because one aspect of acquisition reform was to provide contractors relief from Government-unique terms and conditions. [Ref. 29] One of the contractors stated, "Too liberal. Response was to throw away everything we knew and proceed blindly. The move to acquisition reform was not well thought out, and companies reacted blindly." Another contractor said, "Design Engineers have other priorities which often conflict with the selection of highly reliable parts."

Through all the interviews, one positive theme emerged from the discussions of acquisition reform. That was the use of IPTs. Concurrent engineering and the use of IPTs were mentioned as a method that has reduced some of the risks that were created. It did this in two ways: 1) by increasing the flow of communication, and 2) by involving parts and materials engineers in the earlier stages of the design.

3. Commercial Industry

This section analyzes the techniques that commercial industry uses to manage parts, materials, and processes and which, if any, DoD could adopt. The responses here varied greatly. A number of the interview subjects stated that they were unfamiliar with commercial industry's practices. It is apparent that commercial industry has not, as envisioned, stepped up and developed "best practices" or initiatives to replace part and material military standards and specifications. The common theme among the individuals who did answer this question was that commercial industry does not really do anything differently from the military. In fact, it appears that commercial industry leverages off the DoD for part and material requirements and testing. When something is done differently, such as special testing, it is because commercial industry operates in a more flexible environment. It is also apparent that commercial industry is a different type of business. Because commercial businesses are a bigger part of the market, they have more leverage with suppliers. Also, depending on the market impact, they also can be more tolerant of failures. Due to safety and readiness reasons, the military is typically not as tolerant of failures.

As might be expected from the above responses, the subjects did not think that the military could use very many commercial techniques. In fact, the first common theme that emerged was that the military already leverages commercial practices, such as concurrent engineering and IPTs. The other theme is that the DoD does not want to use some commercial practices because of the differences between the two markets. The military application environment is much more severe than the typical commercial application. One person said, "If we are developing a system that is to be deployed in [a] very harsh military environment with fairly lengthy life cycles, then we need to be very careful what techniques we allow." Overall, there seemed to be agreement that the DoD was already leveraging off commercial practices where it was practical.

4. Mitigating PM&P Risk

This section analyzes the tools and practices that a PM can use to mitigate part, material, and process risks. The purpose of this question was to find synergy among the experts with regard to managing a highly reliable PM&P Program. Table 8 provides a summary of the most frequent responses.

The Top Things A Program Manager Can Do To Mitigate PM&P Risk And Maximize Reliability In The Design
Provide adequate funding for a PM&P Program that includes testing at the part and material level.
Develop a comprehensive PM&P Program as early as possible in the system life cycle.
Ensure that adequate parts, materials, and process requirements are placed in contracts.
Involve PM&P experts early in the process.
Implement a FRACAS down to part and material level.
Monitor and emphasize communication with suppliers.
Utilize IPTs, including a PM&P IPT.

Table 8. The Top Things A Program Manager Can Do To Mitigate PM&P Risk

It was interesting that none of the responses had anything to do with the tools and techniques mentioned earlier. Three main themes developed: 1) establish a PM&P Program early in the system life cycle that includes testing at the part and material level; 2) institute strong management support (funding and enforcement); and 3) make communication between all parties a part of the process.

5. Interface with Logistics

This section analyzes how much and what kind of input the PM gets from the Logistics Manager in a PM&P Program. The purpose of this series of questions was twofold; it was an attempt to get an indication of the level of support being provided and then to find out how this support could be improved. From the list of responses in Chapter III, it is readily apparent there is little support from the LM on part, material, and process issues. Only one of the interview subjects even knew of a program where the LM was involved

There was also a resounding consensus that the level of support needs to be improved. Quite a few interviewees commented that the LM has expertise in fielded equipment and should share this information with the design team. Answers such as "the LM understands the importance of reliability" and "they could provide better feedback at the part level, from the field and depots" demonstrate that there is a need for this information.

As far as the usefulness of the input from the LM is concerned, there was a mixed reaction. There typically was no answer given for these two questions because of the lack of contribution from the LM. On the rare occasions that there was input from the LM, some thought it useful and some did not. The answers indicated that education of the logistics personnel is a key issue. One person responded that "the logistics group does not have the expertise required to impact the early design" and that "logistics managers appear to be lacking the technical skills needed to impact the early design." All indications are that logistics is currently not a part of the design process, where they could have the most impact.

D. LESSONS LEARNED

The following lessons can be extracted from the literature review and the interview responses.

1. "Design in" Reliability Using Highly Reliable Parts, Materials, and Processes

Achieving reliable, available and maintainable systems requires a disciplined systems engineering approach that starts early on in a program. Reliability can be achieved with the help of highly reliable parts, materials, and processes. It is not something that can be tested in later; it must be part of the design process while its still cost-effective.

2. Know And Understand Your Part And Material Application Requirements

There needs to be a clear determination of the system performance requirements, including reliability. The system requirements will get allocated to the lowest levels in the design. The impacts of not establishing a proper requirement will reverberate down to the part and material level.

3. Test At All Levels of the Design; Test Early; Test Often

The ability to design a reliable system requires early and continuous testing from the system level down to the parts and materials that make up the system. This testing is necessary in order to verify and monitor successful achievement of all the performance requirements, including reliability.

4. Know Your Part Suppliers

Reliability issues are not always at the system or Line Replaceable Unit (LRU) level. Details are required all the way down to the part and material level. A microcircuit the size of a penny can end up causing a multi-million-dollar weapon system to fail. Attention to the underlying manufacturing design and manufacturing processes of the contractor, their subcontractors, and vendors are needed to ensure part and material reliability.

5. Know And Understand The Inherent Design Of The Parts

Predicted performance, even at the part and material level, can be overstated. Apply a null hypothesis to these claims—i.e., they are untrue until proven otherwise in the form of valid test results with confidence in the numbers. Just because a supplier claims something on the data sheet does not mean that the product has been verified at those parameters. Use available data if it is applicable to your system, but always have a contractor prove his/her reliability claims, even at the part and material level.

6. Communication is a Key Part of a Successful PM&P Program

Successful communications will ensure the best possible outcome of any plan or program, and this is no different for a PM&P Program. This will require communication and coordination among customers, design engineers, logisticians, contractors, etc. A program with an atmosphere of open dialogue and communication is well on its way to achieving its long-term goals.

E. SUMMARY

The analysis in this chapter provides a valuable insight into the issues that affect the use of highly reliable parts, materials and processes in weapons systems. The chapter provided useful examples and a set of factors that are used to mitigate the risk of using unreliable parts and materials. The analysis was structured around five management themes and attempted to pinpoint either practices to implement in a program, or common pitfalls that PM should avoid. Finally, the chapter outlined lessons learned from the interview process and the background data gathered as part of this research. Chapter V summarizes this topic, draws conclusions, and makes recommendations.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

This thesis evaluated the current process for managing PM&P Programs on weapon systems and identified some of the common challenges, pitfalls, and lessons learned. The key issues and challenges were derived from interviews with individuals responsible for implementing PM&P Programs within the Navy, Air Force, and Army and with their contractors on weapon system programs.

This chapter offers conclusions and recommendations for managing PM&P Programs. It also identifies the correlation between highly reliable parts and materials, as well as overall reliability and critical tactics and strategies that PMs and LMs can use to maximize the inherent reliabilities of system components. These conclusions and recommendations are based upon research analysis and survey responses. This chapter then provides brief answers to the primary and secondary research questions and, finally, makes recommendations for further study.

B. CONCLUSIONS

Based on the literature review and an analysis of interview results, the researcher has drawn the following conclusions:

1. Idealistic Reliability Estimates from Contractors Appear to be Systemic in Weapon Programs

One of the greatest challenges facing a weapon system program can be establishing the reliability of the equipment. Program and Logistics Managers must deal with unrealistic reliability estimates from contractors, who are under pressure to win and maintain contracts. The impact of a flawed figure of merit is twofold. Not only will the weapon system be considered a failure during testing, but the development of a sustainment package based on a flawed reliability factor also will produce sparing shortages, test equipment shortages, and decreased readiness.

2. Highly Reliable Parts, Materials, and Processes are a Fundamental Part of Highly Reliable Weapon Systems

Simply stated, highly reliable parts, materials, and processes are the building blocks of a highly reliable weapon system. While the system design approach is largely responsible for the weapon system's functional performance, reliable parts and materials are essential. Therefore, to insure that the reliability performance is being met, one has to consider and evaluate part and material requirements, their implementation and verification, and the requirements translation to the lowest part, material and process applied in the system.

3. Successful Communication is a Vital Part of Optimizing the Inherent Reliability of a Weapon System

Communication must be emphasized at all levels. Communication is a tool that can assist the program office in avoiding design failures. All team members must be aware of the costs of disorganization and poor communication. A weapon system program must establish an atmosphere of open dialogue and require personnel to participate in all assigned IPT meetings.

4. A PM&P Program Plan is a Critical Element in the Design of a Highly Reliable Weapon System

There must be a clear determination of the system performance requirements, including reliability. The system requirements will get allocated to the lowest levels in the design. The impacts of not establishing a proper requirement will reverberate down to the part and material level. A PM&P Program Plan is critical because it will help a program know and understand part and material requirements.

5. Part and Material Testing is an Essential Part of Weapon System Development

The ability to design a reliable system requires early and continuous testing from the system level down to the parts and materials that make up the system. This testing is necessary in order to verify and monitor successful achievement of all the performance requirements, including reliability. Programs often fail to perform part and material testing due to inadequate upfront reliability testing and a lack of funding.

6. Continuous Monitoring of Suppliers is Crucial to High Reliability

Programs need to monitor suppliers for changes to parts, materials, and processes that would affect performance. Attention to the underlying manufacturing design and manufacturing processes of the contractor, their subcontractors, and vendors is needed to ensure part and material reliability

C. RECOMMENDATIONS

The following recommendations can be used to maximize the inherent reliability performance of weapon systems.

1. Establish a True (Measured) Reliability Figure of Merit, then Support that Number and not Unrealistic Contractor Estimates

During initial acquisition, contractor engineers provide reliability estimates that are critical in establishing sparing levels and technical support criteria. Experience has shown that contractors typically use optimistic reliability predictions. [Ref. 17] Weapon systems must dedicate the necessary resources to verify the true reliability and then support that number. The failure of a weapon system to achieve its projected reliability levels will have a severe impact on the operation and support (O&S) costs and operational availability (Ao).

2. "Design in" Reliability Using Highly Reliable Parts, Materials, and Processes

The use of highly reliable parts, materials, and processes to "design in" inherent reliability can be facilitated with the following two techniques. First, weapon system programs should establish a Part and Material Review Board (PMRB). The PMRB would be responsible for implementing effective parts and materials management and for promoting commonality of parts and processes across product lines. The PMRB can enhance the implementation of concurrent engineering, by including representatives from seven areas: 1) design engineering; 2) procurement; 3) manufacturing; 4) quality; 5) subcontractors and suppliers; 6) customer; and 7) logistics.

Weapon system programs should also require their contractors to establish a FRACAS that requires root-cause corrective action at the part and material level. A FRACAS is an important tool in the solution of complex reliability problems. A well-defined FRACAS will catch part and material problems early in the life cycle, before they cause high-profile failures.

3. Weapon System Programs Must Promote Logistics Involvement

Most weapon system programs already use IPTs as a management technique. They need to take the next step and involve the logistics manager early in the system life cycle. Most weapon system programs do not have the Logistics Manager involved with the PM&P Program. However, weapon system programs should make sure that a logistician is a permanent member on any part- and material-related IPT.

4. Know and Understand Part and Material Application Requirements

As early as possible in the system life cycle, require all contractors and subcontractors to develop a comprehensive PM&P Plan based on MIL-HDBK-512 or American Institute of Aeronautics and Astronautics (AIAA) industry standard document AIAA R-100. This PM&P Plan should: 1) explicitly define a PM&P Program that will ensure the use of parts that meet contractual requirements; 2) reduce proliferation of parts through standardization; and 3) enhance equipment reliability and supportability.

5. Require and Support Part and Material Testing

Weapon system programs must recognize that they should perform qualification testing at the part and material level. Funds should be allocated for independent testing of piece parts and materials. The component engineers must know that there are no barriers to testing of parts where they feel it is required. The PM&P Program IPT should establish design review criteria and make them a standard part of the design review process.

Weapon system programs also must plan for PM&P Program activities. Funding is often not allocated to the PM&P Program or is later withdrawn because of competing priorities. A long-term approach will help ensure that the PM&P Program has adequate funding and support.

6. Continuously Monitor Suppliers

A weapon system program must ensure that contract requirements flow down to subcontractors, suppliers, and distributors. PM&P Program personnel must participate in the technical evaluation of suppliers and in the review and approval of suppliers' manufacturing processes and parts changes. DoD should re-evaluate the policy of strict adherence to performance-based requirements and require contractors to participate in programs like GIDEP. Since GIDEP's inception, participants have reported **more than $1 BILLION** in prevention of unplanned expenditures. This means that, without GIDEP, participants could have *potentially* realized additional expenses exceeding $1 billion. [Ref. 30]

D. ANSWERS TO RESEARCH QUESTIONS

Primary Research Question

How is the selection of highly reliable parts and materials an essential part of the overall reliability development process, and what critical tactics and strategies can Program and Logistics Managers use to maximize the inherent reliabilities of system components?

Achieving reliable, available and maintainable systems requires a disciplined systems engineering approach that starts early on in a program. Maximizing system reliability is something that can be achieved with the help of highly reliable parts, materials, and processes. Reliability cannot be tested in later, but must be part of the design process while it is still cost effective. A microcircuit the size of a penny can end up causing an entire multimillion-dollar weapon system to fail. The following are recommended steps a Program Manager should consider taking in an effort to optimize weapon system inherent reliability:

Provide adequate funding for a PM&P Program that includes testing at the part and material level.

Develop a comprehensive PM&P Program as early as possible in the system life cycle.

Ensure that adequate parts, materials, and process requirements are placed in contracts.

Involve PM&P experts early in the process.

Implement a FRACAS down to the part and material level.

Monitor and emphasize communication with suppliers.

Utilize IPTs, including a PM&P IPT.

The following are recommended steps a Logistics Manager should consider taking in an effort to optimize weapon system inherent reliability:

Make sure that the design IPTs understand the logistics impacts of the early design.

Make sure that the PM understands the logistics impacts and importance of reliability.

Provide feedback at the part and material level, from the field and depots.

Provide education for your people. Most logisticians lack the technical skills needed to impact the early design.

Subsidiary Research Questions

The following subsidiary questions focused the author's efforts in answering in the primary research question.

a. What technology, tools, and techniques are available to ensure the proper selection of reliable parts and materials?

Many tools and techniques can be used to insure the proper selection of reliable parts and materials. Listed below are the most frequently utilized design tools to ensure that reliability is "built in" early in the design of a weapons system:

Reliability Prediction Analysis

Circuit Tolerance Analysis

Sneak Circuit Analysis

Physics of Failure Tools

Part Derating

Government Industry Data Exchange Program

b. How has acquisition reform changed the way a PM&P Program is managed?

Acquisition reform has significantly increased the risks to PM&P Programs. Prior to acquisition reform, a PM&P Program was strictly controlled by the Government through contractually required military specifications and standards. After acquisition reform, military specifications and standards could no longer be used. There was no longer one uniform process; there was the loss of lessons learned intrinsic to the military specifications and standards, and all requirements had to be specified in performance-based terminology. This has placed a premium on the ability to communicate. Concurrent engineering and the use of IPTs are powerful management techniques that can reduce some of the risks that were created.

c. To what extent does commercial industry differ in its approach to part and material selection, and can the military leverage these best practices to improve performance in military systems?

The DoD already leverages off commercial practices, where practical, in its part and material selection. It also is apparent that commercial industry has not stepped up and developed "best practices" or initiatives to replace part and material military standards and specifications. Where part and material requirements and testing are concerned, commercial industry leverages off the DoD. Most of the differences between the military and commercial industry can be attributed to a different business environment. There are also basic design differences between parts and materials used for military vs. commercial applications. Most military designs are used in very harsh environments, whereas most commercial components are designed for a protected environment. Commercial parts and materials many times are not subjected to shock, vibration, pressure or moisture and have an application life span of less than five years.

The military environment is much more severe and requires parts and materials with an application life span of ten to 20 years. [Ref. 31]

d. How can Program and Logistics Managers mitigate part and material risks?

The most important thing a PM can do to mitigate part and material risks is to make maximum use of IPTs. IPTs will increase the flow of communication and promote the involvement of parts and materials engineers at the earlier stages of design. The most important thing an LM can do to mitigate part and material risks is to get involved early in the IPT process. The LMs also need to develop the technical expertise to influence the design of the product.

E. RECOMMENDATIONS FOR FURTHER STUDY

The following are recommended topics for additional research:

1. Evaluate the kind of data currently collected in the field and determine how to best provide feedback to a PM&P Program so there can be improvement.
2. Analyze the best methods and approaches for incentivizing reliability, not only in contracts, but also in project offices.
3. Perform a more complete study on how commercial industry manages parts, materials, and processes. Assess if anything can be adapted for weapon system development.

F. THESIS SUMMARY

Managing reliability performance on a weapon system demands the implementation of effective management strategies that balance cost, schedule and performance against reliability risks over the course of a weapon system's development and fielding. Although reliability is composed of many parts, one of the keys resides in early identification of upfront cost-effective opportunities for improving reliability performance, as well as mitigation of associated risks during design. Predictable and reliable performance in the field is the desired end state.

Highly reliable parts, materials, and processes are the building blocks of a highly reliable weapon system. While the system design approach is largely responsible for the weapon system's functional performance, the PM&P Program approach is responsible for a large part of the weapon system's reliability performance. Therefore, to insure that the reliability performance is being met, one has to consider and evaluate the PM&P Program requirements, its implementation and verification, and the requirements translation to the lowest part, material and process applied in the system. The goal of a PM&P Program is the selection of parts, materials, and processes that can withstand the manufacturing environment and reliably perform the needed function for the design life of the product in the intended environment.

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